Dow Energy Materials:
Developing and Commercializing Energy Storage Solutions in Michigan

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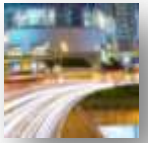
Outline

The Energy Challenge



Energy Storage as a Solution

Dow Energy Materials

Themes of Sustainable Chemistry & Engineering

- Reduced Hazard
- Atom Economy
- Energy Footprint
- Holistic Design

Manufacturing in Michigan

Energy is a key Megatrend shaping the Future

Health & Nutrition

- Agriculture
- Functional Foods
- Healthcare

Energy

- Alternative Energy & Feedstocks
- Energy Production & Efficiency
- Energy Storage

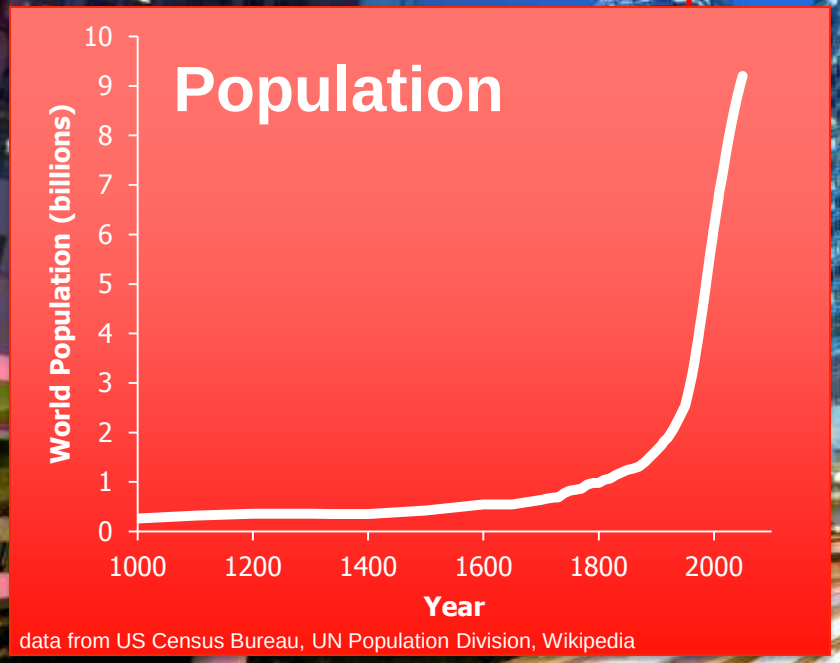
Transportation & Infrastructure

- Construction
- Transportation
- Water

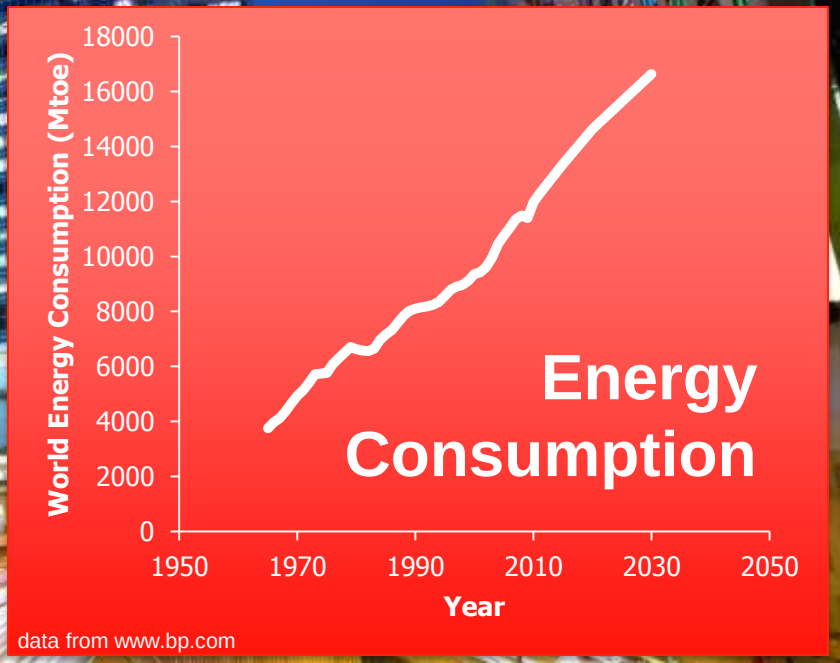
Consumerism

- Apparel & Furnishings
- Electronics & Communications
- Home & Personal Care

Sustainability: Looking Forward



data from US Census Bureau, UN Population Division, Wikipedia

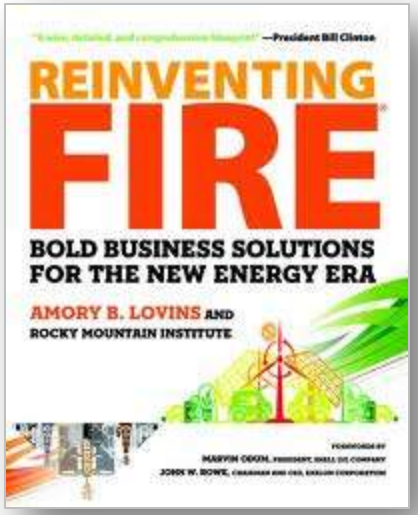


data from www.bp.com

Energy Storage: A Part of the Solution

Energy Storage can enable:

- Optimum use of renewable energy
- Smart Grid technology
- Low GHG energy



"the shift to electric autos is going to be as game-changing as shifting from typewriters to computers… of course computers and electronics are now America's biggest industry, while typewriter makers have vanished"

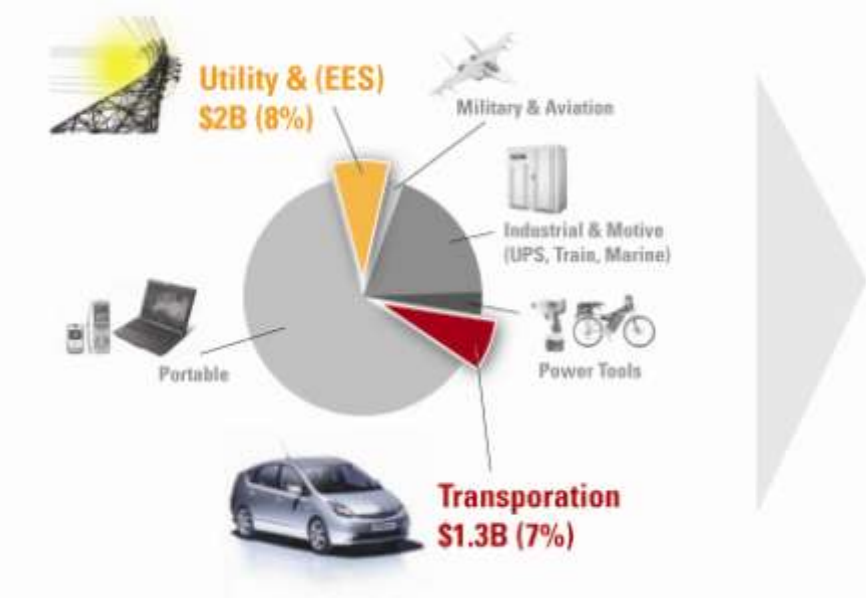
– Amory Lovins

Chief Scientist, Rocky Mountain Institute

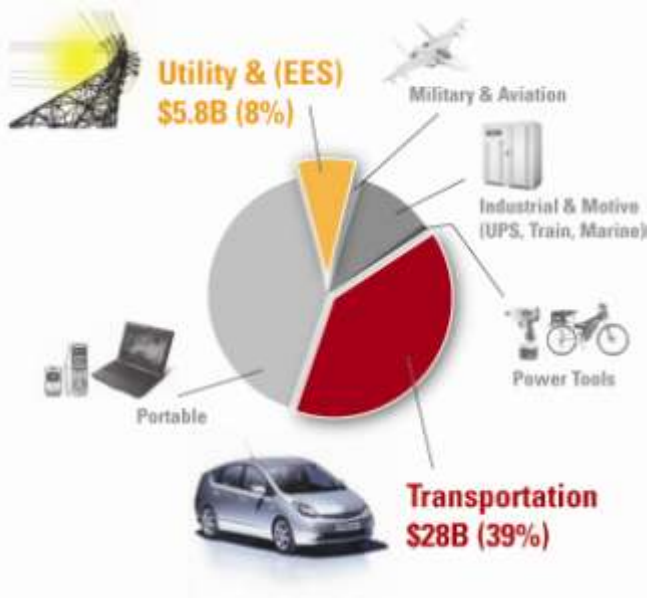
http://www.ted.com/talks/amory_lovins_a_50_year_plan_for_energy.html

Energy Storage Market

Today - $24B



2020 - $74B

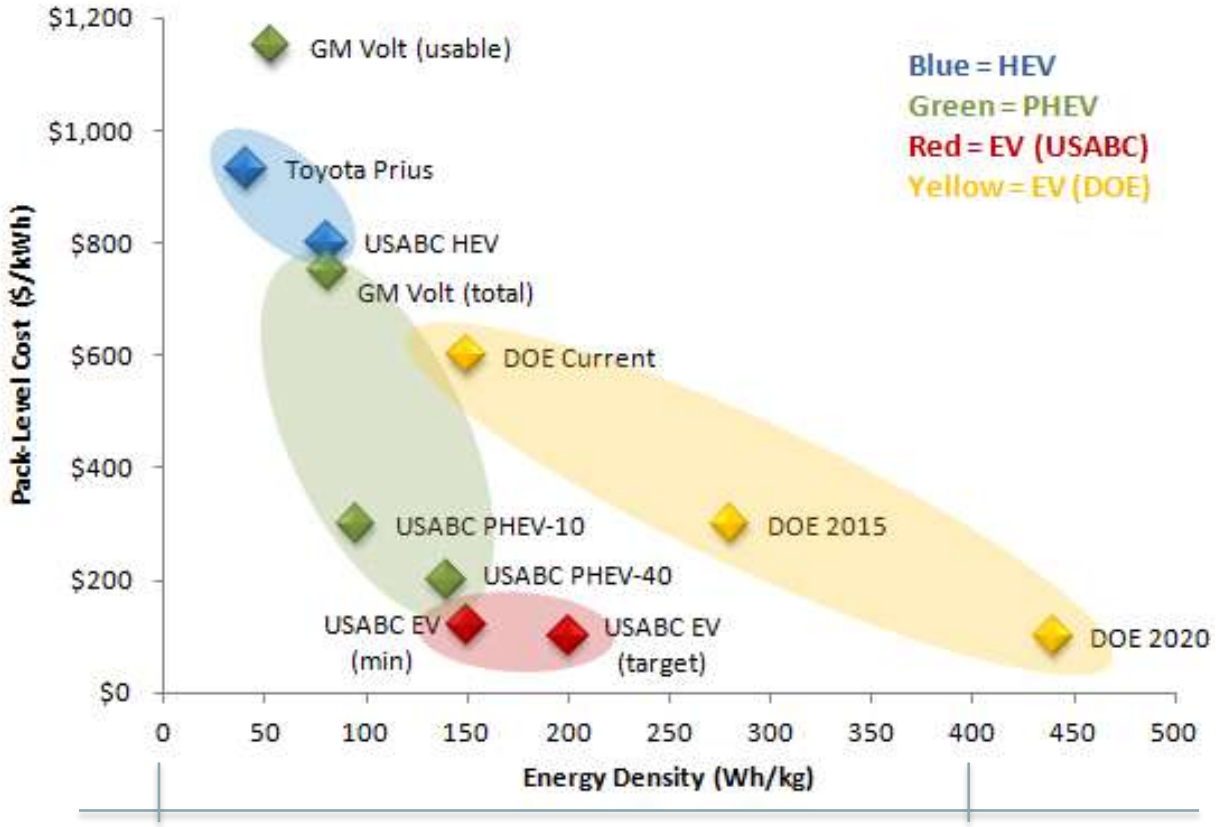


Utilities and Automotive: $3.3B

Utilities and Automotive: $33.8B

Rechargeable lithium-ion battery expected to be the dominant technology (growth at 5X GDP)

xEV Pack Level Energy Density and Cost Targets



Practical Limit* of Lithium Ion Technology

Disruptive Technology

Key challenges:

- **Higher Energy Density**
- **Safety**
- **Longer Life**
- **Lower Cost to Manufacture**

* Assuming a practical limit of 2 MJ/kg at the cell level and a factor of 0.75 for pack level construction.

Dow Energy Materials

Dow Energy Materials strives to be a customer-focused, multi-component material supplier to battery manufacturers.

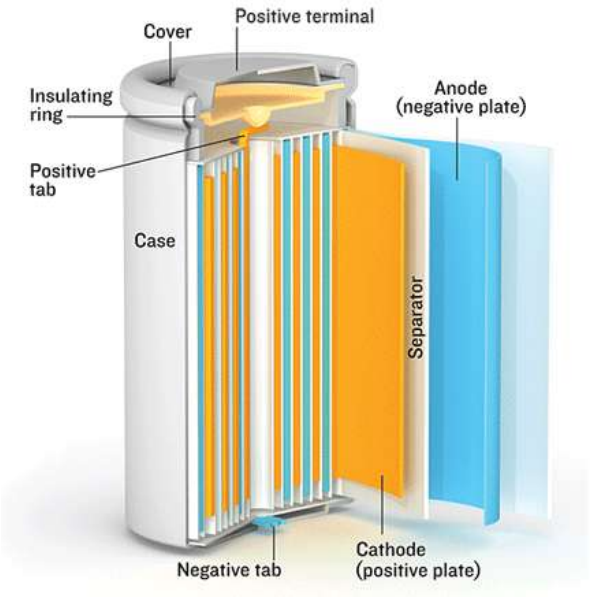
Three Keys To Succeed:

1. Improve Battery Cell Performance through **Differentiated Materials**
2. Drive Down **Cost to Manufacture**
3. Offer **Integrated Portfolio** of Battery Materials

Li-Ion Battery Chain

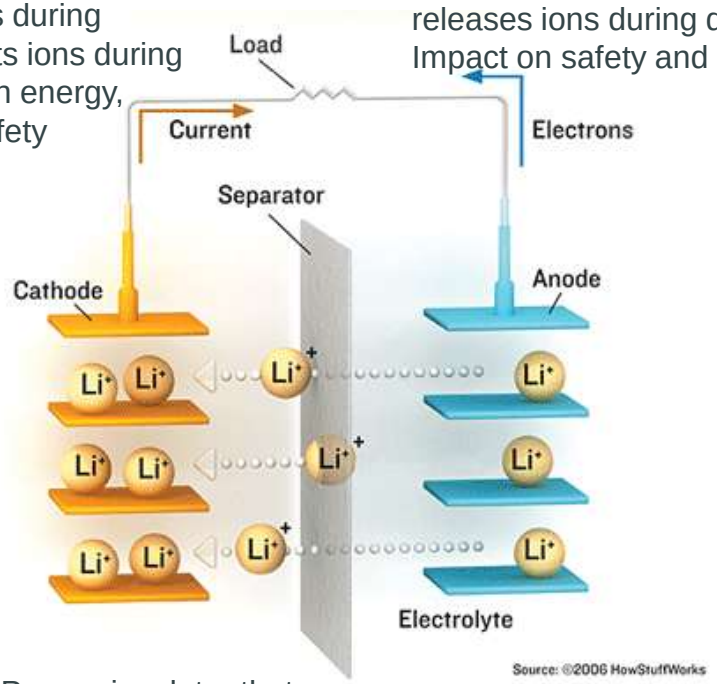
Mining → Materials → Components → Cells → Packs → Application

Li-Ion Battery: A System



Cathode: Electrode that releases lithium ions during charging and accepts ions during discharge, Impact on energy, power, cycle and safety

Anode: Electrode that accepts lithium ions during charging and releases ions during discharge, Impact on safety and cycle life

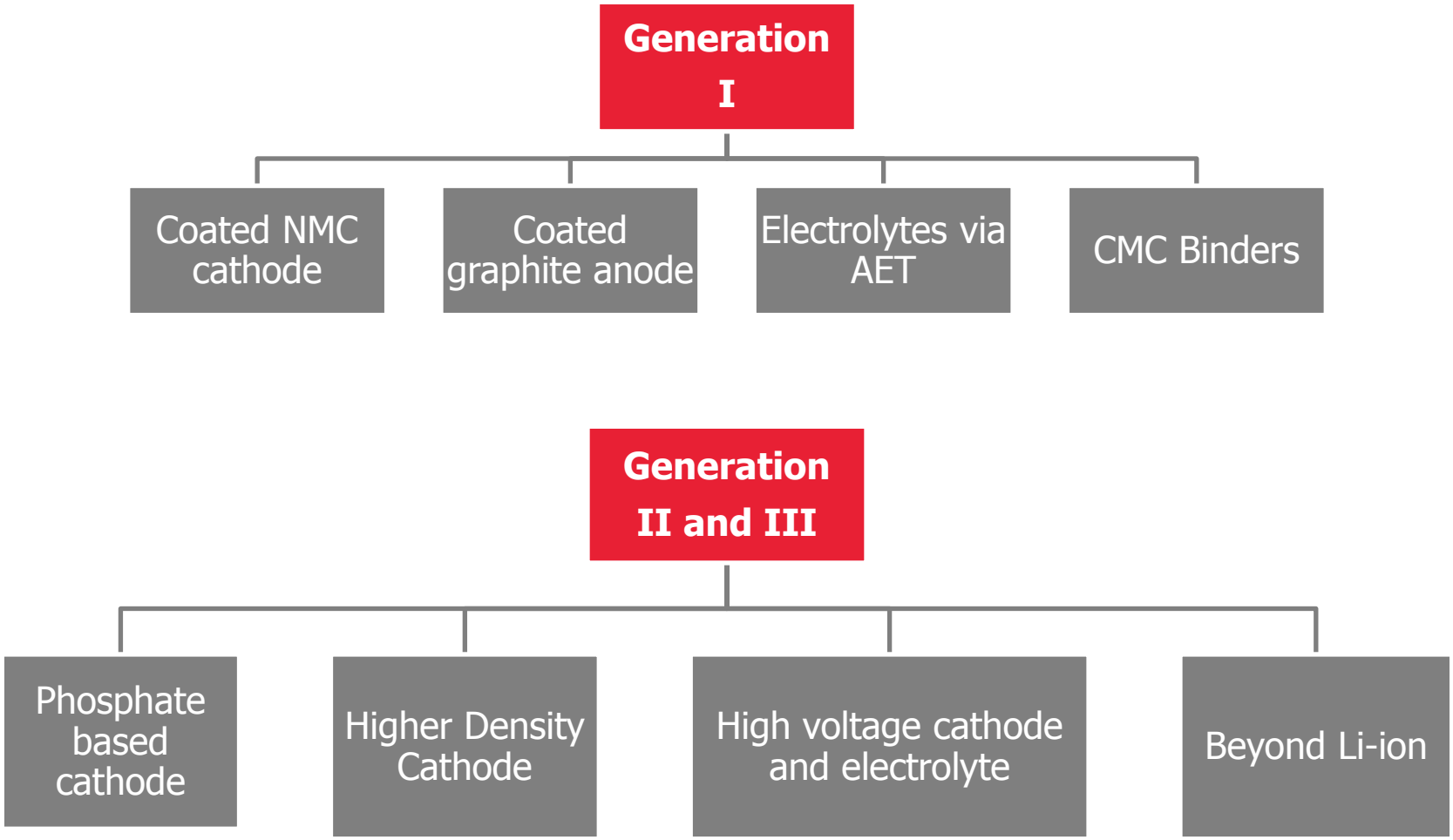


Separator: Porous insulator that allows ionic contact between the cathode and anode via electrolyte solution, Impact on safety

Electrolyte: Organic solution that enables the transfer of lithium ions between cathode and anode, Impact on temperature performance and cycle life

System optimization/pairing of materials have the potential to increase energy density and reduce cost

Dow Energy Materials: Materials Development



DEM R&D Cathode Materials Portfolio: Transportation

		Energy	Power	Life*	Safety	Cost
PHEV, EV	**NMC** $LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	2000-3000	++	$20-30 / kWh
PHEV, EV	**Coated NMC** $LFP/LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	3000-4000	++	$25-35 / kWh
(P)HEV	**LMFP** $LiMn_xFe_{1-x}PO_4$	585 Wh/kg	+++	1000-2000	+++	$10-20 / kWh
EV	**LNMO** $LiNi_xMn_{2-x}O_4$	685 Wh/kg	+++	200-400	++	$15-25 / kWh
EV	**LL-NMC** $Li(LiNi_xMn_yCo_{1-x-y}O_2)$	900 Wh/kg	++	100-200	??	$10-20 / kWh

Industry Average Values

DEM R&D Cathode Materials Portfolio:
Energy Storage Systems

	Energy	Power	Life*	Safety	Cost
NMC $LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	2000-3000	++	$20-30 / kWh
Coated NMC $LFP/LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	3000-4000	++	$25-35 / kWh
LMFP $LiMn_xFe_{1-x}PO_4$	585 Wh/kg	+++	1000-2000	+++	$10-20 / kWh
w/LTO **LNMO** $LiNi_xMn_{2-x}O_4$	685 Wh/kg	+++	200-400	++	$15-25 / kWh
LL-NMC $Li(LiNi_xMn_yCo_{1-x-y}O_2)$	900 Wh/kg	++	100-200	??	$10-20 / kWh

Industry Average Values

DEM R&D Cathode Materials Portfolio:
Consumer Electronics

	Energy	Power	Life*	Safety	Cost
NMC $LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	2000-3000	++	$20-30 / kWh
Coated NMC $LFP/LiNi_xMn_yCo_{1-x-y}O_2$	605 Wh/kg	++	3000-4000	++	$25-35 / kWh
LMFP $LiMn_xFe_{1-x}PO_4$	585 Wh/kg	+++	1000-2000	+++	$10-20 / kWh
LNMO $LiNi_xMn_{2-x}O_4$	685 Wh/kg	+++	200-400	++	$15-25 / kWh
LL-NMC $Li(LiNi_xMn_yCo_{1-x-y}O_2)$	900 Wh/kg	++	100-200	??	$10-20 / kWh

Industry Average Values

Themes of Sustainable Chemistry & Engineering

12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

33 Principles Framed as Four Simple Themes!

12 Principles of Green Engineering

1. Inherent Rather Than Circumstantial
2. Prevention Instead of Treatment
3. Design for Separation
4. Maximize Efficiency
5. Output-Pulled Versus Input-Pushed
6. Conserve Complexity
7. Durability Rather Than Immortality
8. Meet Need, Minimize Excess
9. Minimize Material Diversity
10. Integrate Material and Energy Flows
11. Design for Commercial "Afterlife"
12. Renewable Rather Than Depleting

Sandestin Principles of Green Engineering

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life-cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations, and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate, and invent (technologies) to achieve sustainability.
9. Actively engage communities and stakeholders in development of engineering solutions.

Theme: Reduced Hazard in Dow Energy Materials

Minimize the hazards impacting people and the environment

Improving Use Phase Safety

- Material performance: thermal stability, structural stability
- Battery Management System
- Material/battery manufacturers working closely to improve upon safety

Product Stewardship

- Commitment to protect people and the planet
- Product Safety Leadership: one of Dow's 2015 Sustainability Goals
  - will publish Product Safety Assessments for all products by 2015
  - http://www.dow.com/productsafety/

Theme: Atom Economy in Dow Energy Materials

Efficient use of all mass inputs to a product, process, or system

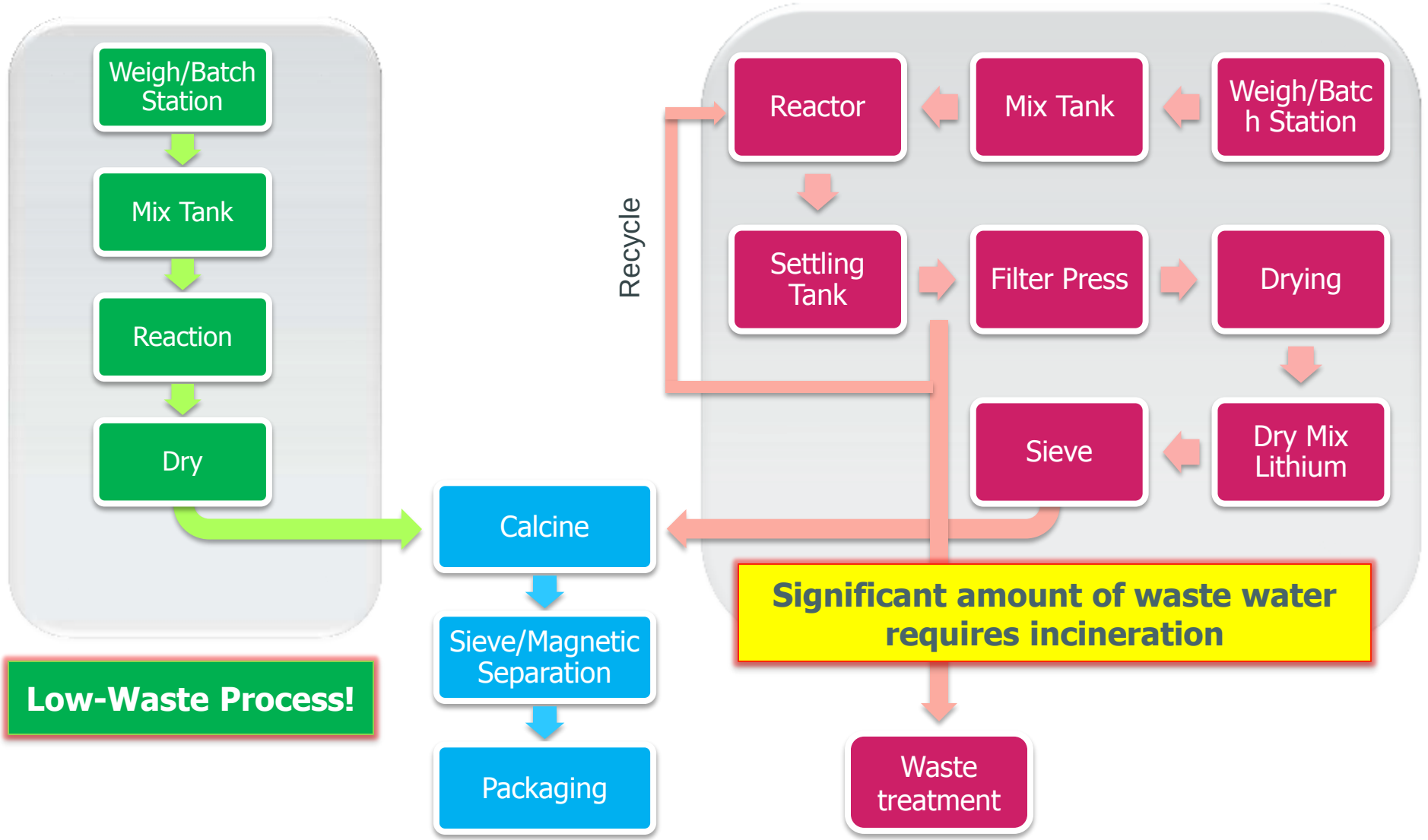
Process Optimization and Simplification by DEM R&D led to significant gains in atom economy and process efficiency

- Process simplified from 11+ steps process to 7 step process
- Waste reduced from 40 MT/MT product to <1 MT/MT product

Delivering the functional unit with less material

- Higher energy density batteries
- Improved battery lifetimes

Atom Economy and Cost Reduction via Process Simplification



Theme: Energy Footprint in Dow Energy Materials

Maximize energy efficiency and consider the source of the energy when evaluating options

Energy efficient manufacturing remains a priority for DEM R&D

The Big Picture: **DEM products enable solutions to Global Energy and GHG Challenges**

- The major energy footprint benefit is outside of DEM's gate
- Improved Li-battery technology critical for enabling Smart Grids
  - Energy Storage Systems
    - Renewables (Solar, Wind, etc.)

Theme: Holistic Design in Dow Energy Materials

Apply life cycle thinking to consider the impacts of products from cradle to grave

Use phase is most significant contribution for DEM!

- Use phase dominates Li-ion battery life cycle impacts for most categories*
- Electricity source is critical to the environmental performance of DEM product applications**
- Consumer behavior also important for determining impact of use phase

* "Lithium-ion Batteries and Nanotechnology for Electric Vehicles: A Life Cycle Assessment", draft report, EPA 744-R-12-001, April 26, 2012

** Samaras and Meisterling, "Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy", *Environ. Sci. Technol*. **2008**, *42*, 3170 - 3176

Theme: Holistic Design in Dow Energy Materials

Apply life cycle thinking to consider the impacts of products from cradle to grave

End of Life: Cradle-to-cradle thinking

- Important issue for all battery materials: Reuse? Recycle? Other options?
- A focus of ACC Lithium Battery Materials Panel*
- Argonne National Lab work** suggests that recycling of some battery materials can reduce life cycle energy consumption

* http://lithium-battery-materials.americanchemistry.com/PDFs/Lithium-Battery-Materials-Summary.pdf

** Dunn et al., "Energy Consumption and Greenhouse Gas Emissions during Automotive Lithium-Ion Battery Production, Assembly, and Recycling", presented at LCA XII, Tacoma, 25 September 2012, http://lcacenter.org/lcaxii/sessions/abstract-dynamic.php?id=563

Dow Energy Materials: Driving Sustainable Manufacturing In Michigan

https://maps.google.com/

Dow Energy Materials is based in Midland, MI

- Business Leadership, Manufacturing, R&D, all in Midland

Advanced Electrolyte Technologies (AET) – DEM's Joint Venture with Ube

- Headquartered in Troy, MI
- Manufacturing in Midland, to be operated by DEM

Dow Kokam – Dow's Joint Venture with Kokam

- Headquartered in Midland
- Manufacturing in Midland

By applying Green Chemistry & Engineering to technology that is motivated by sustainability challenges, we are creating a business that is helping to drive sustainable manufacturing in Michigan!

R&D Capabilities and Manufacturing in Midland, MI

Research and Development

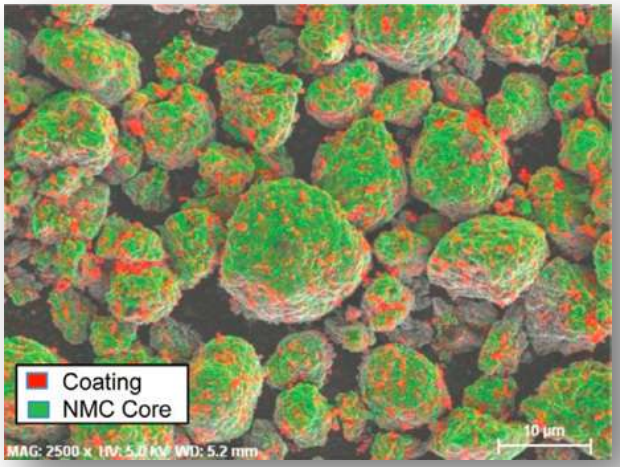
Manufacturing

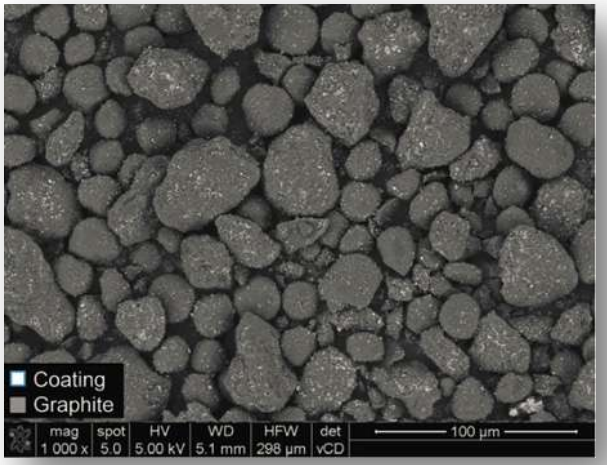
60,000 square feet
2000 T cathode materials
1500 T anode materials
5000 T formulated electrolytes

Leading battery materials technology development and manufacturing here in Michigan!

Summary

- **Dow Energy Materials** is developing advanced battery materials to help solve the world's Energy & GHG challenges
- Application of Dow's **Themes of Sustainable Chemistry & Engineering** continues to be important for business and technology development
- **Life Cycle Thinking** is key: battery Use Phase is key to environmental performance of lithium ion batteries
- DEM is helping to drive **sustainable manufacturing in Michigan**!





Thank You

http://www.dowenergymaterials.com/